The status of the MARE experiment with ^{187}Re and ^{163}Ho isotopes

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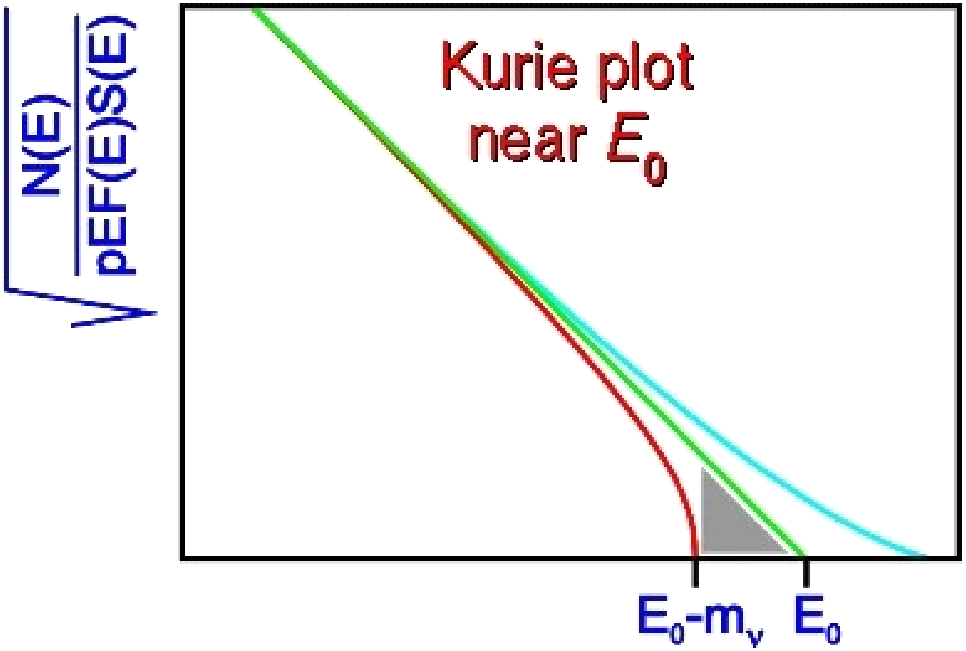
Outline

- Physical motivation and the calorimetric approach
- MARE-1 in Milano
- ^{187}Re
- ^{163}Ho
- The HOLMES project
- MKIDs & ^{163}Ho
- Conclusions

Direct neutrino mass measurement



$m_\nu = (\Sigma m^2_i |U_{ei}|^2)^{1/2}$

kinematics of weak decays

- nuclear beta decays
- use only energy and momentum conservation
- no further assumptions

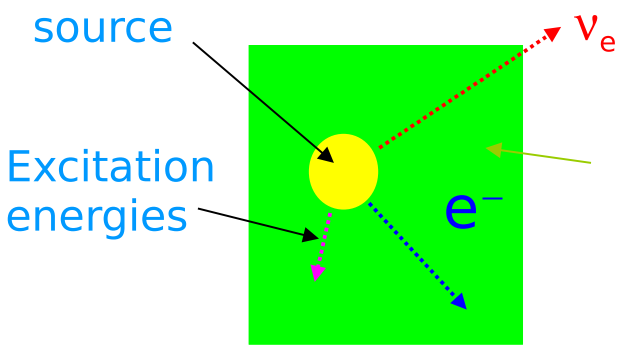
15 eV → ^{187}Re (E_0=2.47keV) & calorimeters
2 eV → ^{3}H (E_0=18.6keV) & spectrometers

General experimental requirements:

- High statistics at the beta spectrum end-point
- High energy resolution ΔE

Calorimetric approach

Calorimeters: source ⊆ detector

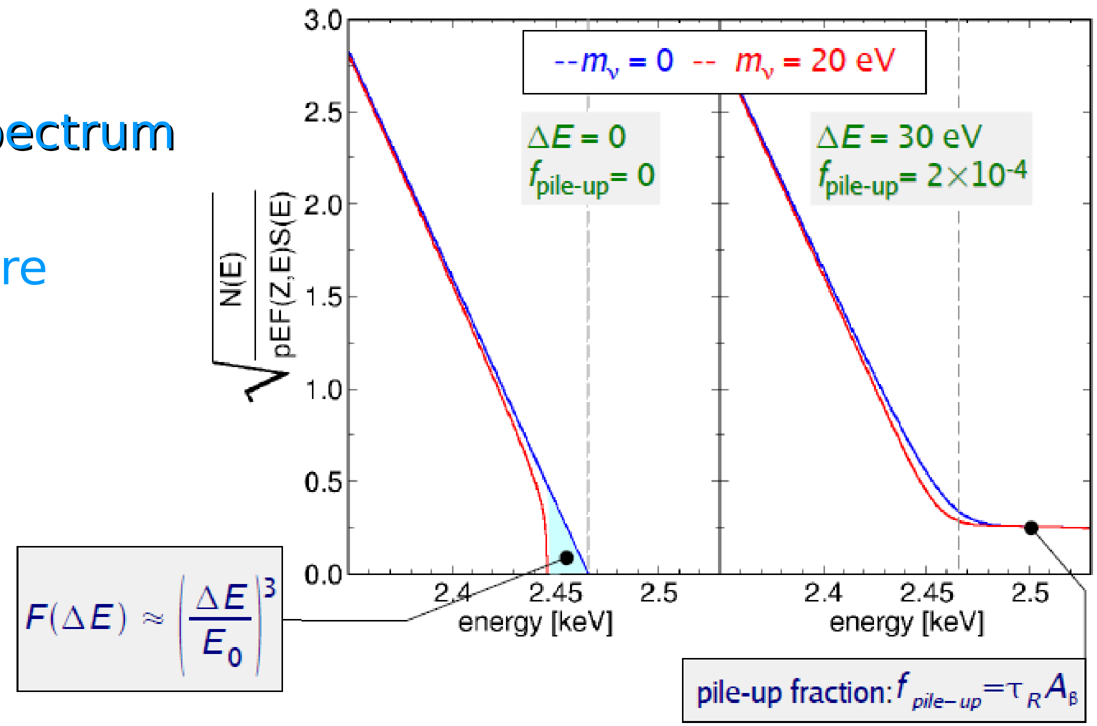


β calorimeter
ideally measures all the energy E released in the decay except for the ν_e energy

✔ no backscattering
✔ no energy losses in the source
✔ no atomic/molecular final state effects
✔ no solid state excitation
✘ limited statistics
✘ pile-up background
✘ spectrum related systematics

Calorimeters measure the **entire spectrum** at once:

- low E_0 β decaying isotopes for more statistics near the end-point
- ^{187}**Re** beta decay:
  - E_0 = 2.5 keV, τ½ = 4×10^{10} y
- other option ^{163}**Ho** EC:
  - E_0 ≈ 2.6 keV, τ½ ≈ 4600 y



MARE

MARE-1: a few eV direct neutrino mass measurement with ^{187}Re .

MARE-1 in Milan: Milano/FBK/Wisconsin/NASA

- $m_\nu < 2$ eV/c^2
- 10^{10} events - 300 sensors
- 8 arrays of Si:P thermistors with $AgReO_4$ absorbers
- energy resolution 25 eV @ 2.6 keV

This experiment is needed:
- because it's the only possible one with present technology
- To investigate systematics in thermal calorimeters

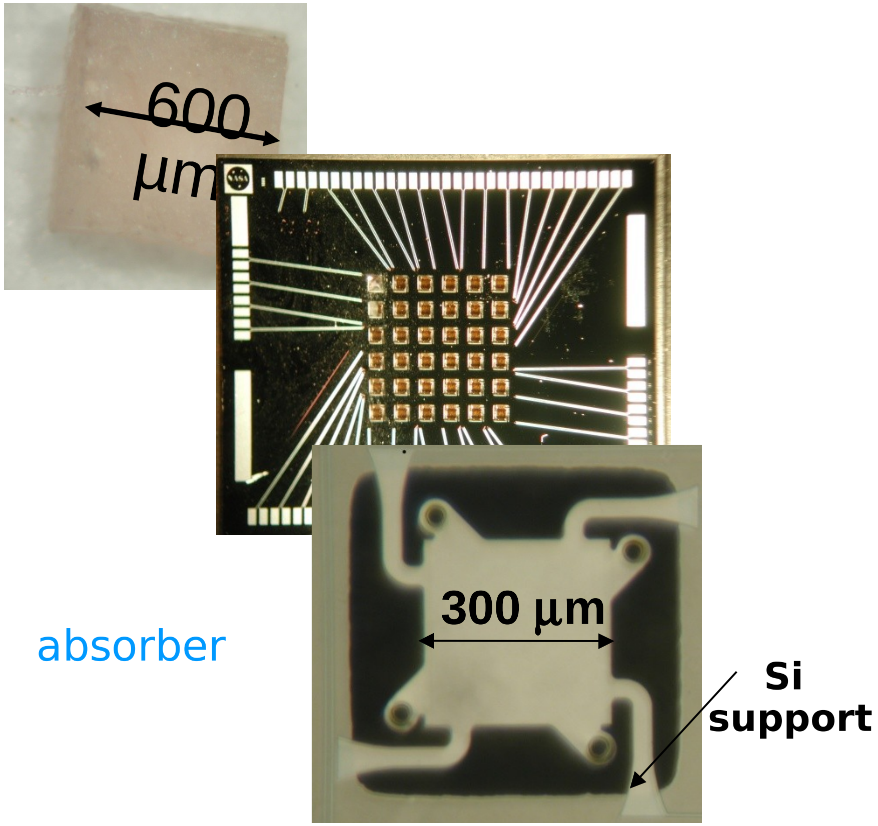
↳ **very important to cross-check spectrometer results**

MARE-1 detectors/^{187}Re

- ^{187}Re β-decay
  - $^{187}Re \rightarrow ^{187}Os + e^- + \nu_e$ E_0=2.47 keV
  - i. a. 63% and τ=42.3 Gy

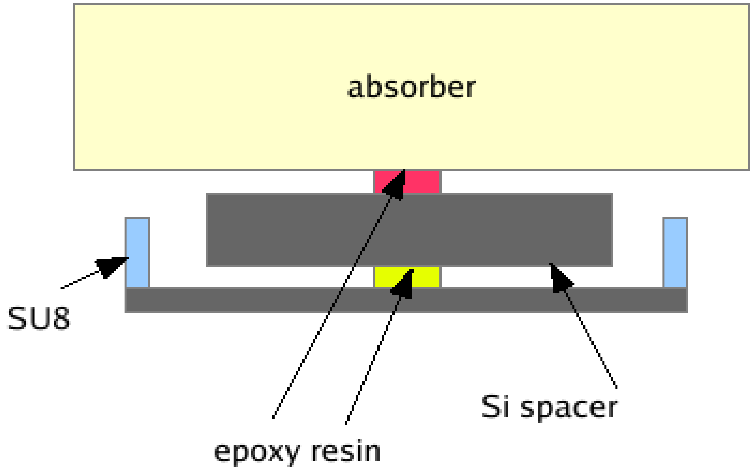
- Single crystal of silver perrhenate ($AgReO_4$)
  - mass ~ 500 μg per pixel (A_β~ 0.3 decay/sec)
  - regular shape (600x600x250 μm³)
  - low heat capacity due to Debye law

- 6x6 array of Si:P semiconductors (NASA-GSFC)
  - pixel: 300x300x1.5 μm³
  - high energy resolution
  - developed for X-ray spectroscopy with HgTe absorber (ASTRO-E2)

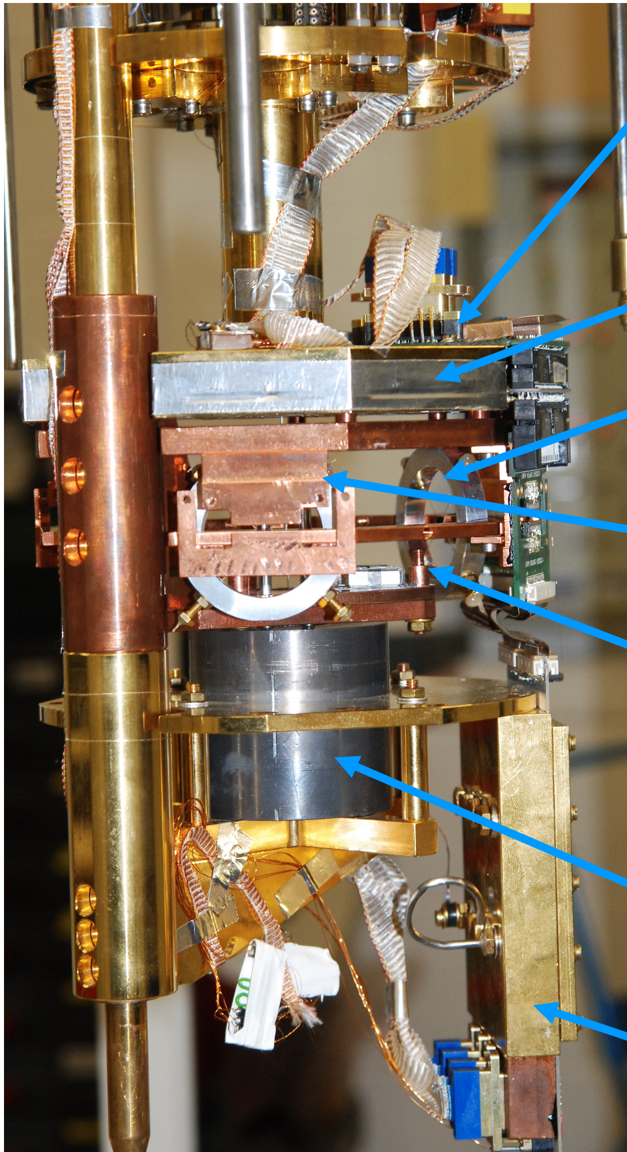


Thermal coupling
- Araldit or ST1266: thermistor/spacer
- ST2850: spacer/$AgReO_4$

First array:
- 6 silicon spacers are attached with **Araldite Normal**
- 10 with **Araldite Rapid**
- 15 with **ST1266**



Cryogenic set-up/^{187}Re



Load Resistence 50 MΩ

Detector holder

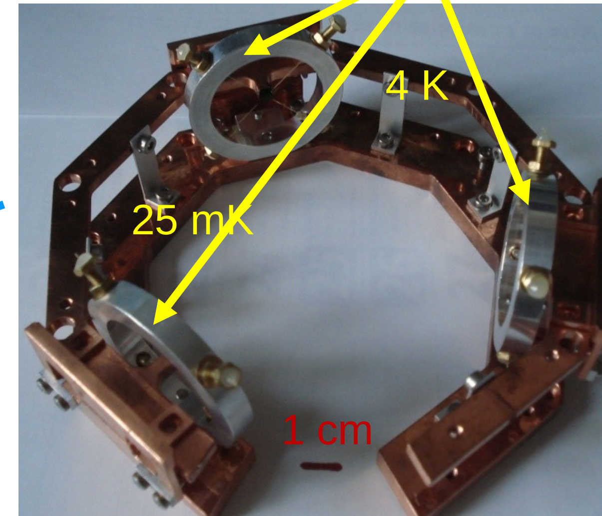
Calibration source ^{55}Fe

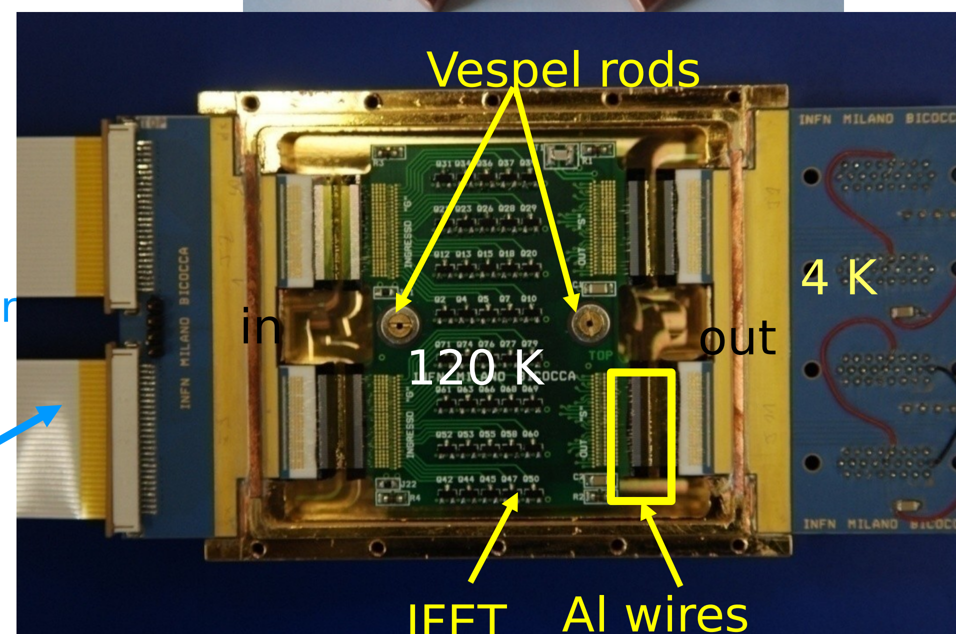
Calibration targets

Pb shield for calibration source

JFET box

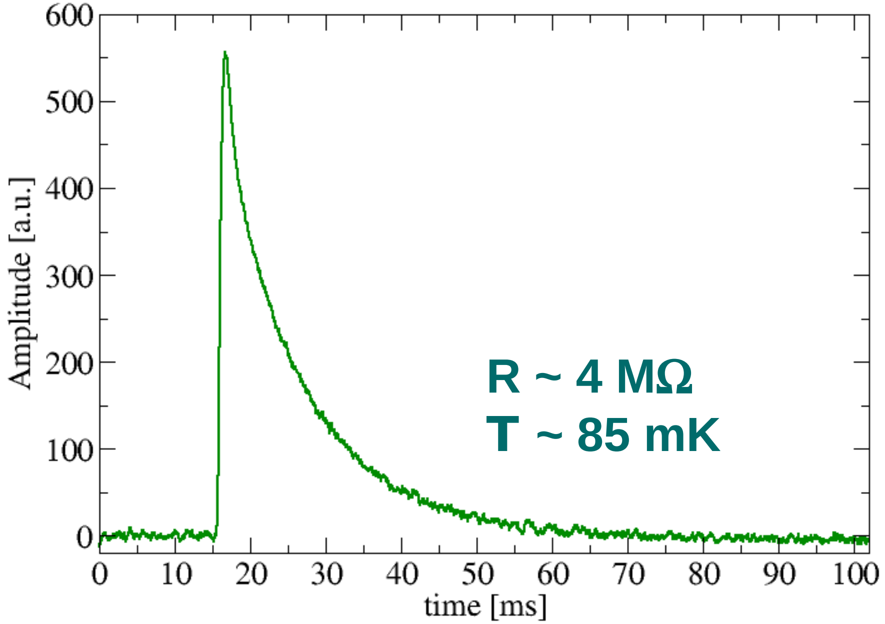
Kevlar crosses

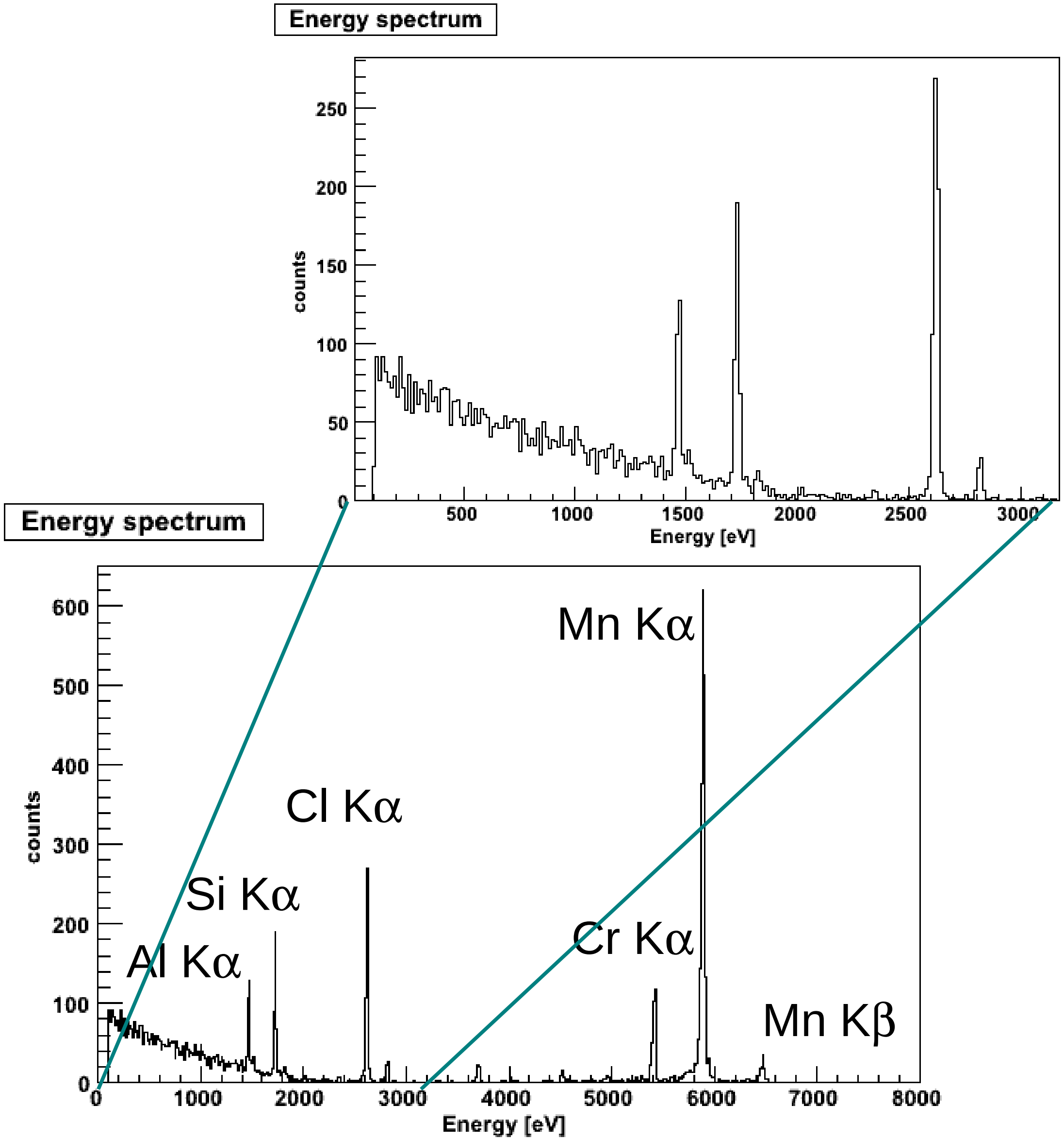




First array/^{187}Re

A run aimed to test the performance of this setup is ongoing, after which the absorbers will be glued also on the second array. With two arrays, a sensitivity of 4.5 eV at 90% C.L. is expected in three years running time.



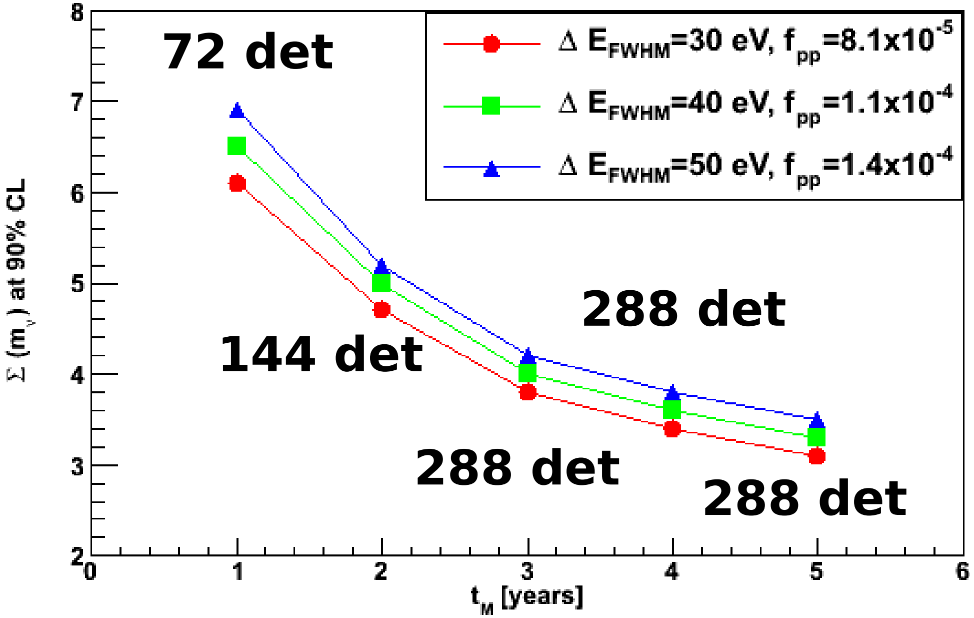


- Working temperature T ≈ 85mK
- $\Delta E \approx$ 28 eV @ 1.5 keV
- $\tau_R \sim 1$ ms

MARE 1 with ^{187}Re: sensitivity

Estimation of the sensitivity on neutrino mass over the years by increasing the detectors number from year to year.

Analytic approach (1st order)



Detectors

$\Delta E_{FWHM} \sim$ 50 eV and $\tau_R \sim$ 500 μs
1 year and 72 channels $\rightarrow \Sigma(m_\nu) \sim$7eV
3 years and 288 channels $\rightarrow \Sigma(m_\nu) \sim$ 4.2eV

$\Delta E_{FWHM} \sim$ 30 eV and $\tau_R \sim$ 300 μs
1 year and 72 channels $\rightarrow \Sigma(m_\nu) \sim$6eV
3 years and 288 channels $\rightarrow \Sigma(m_\nu) \sim$ 3.8eV

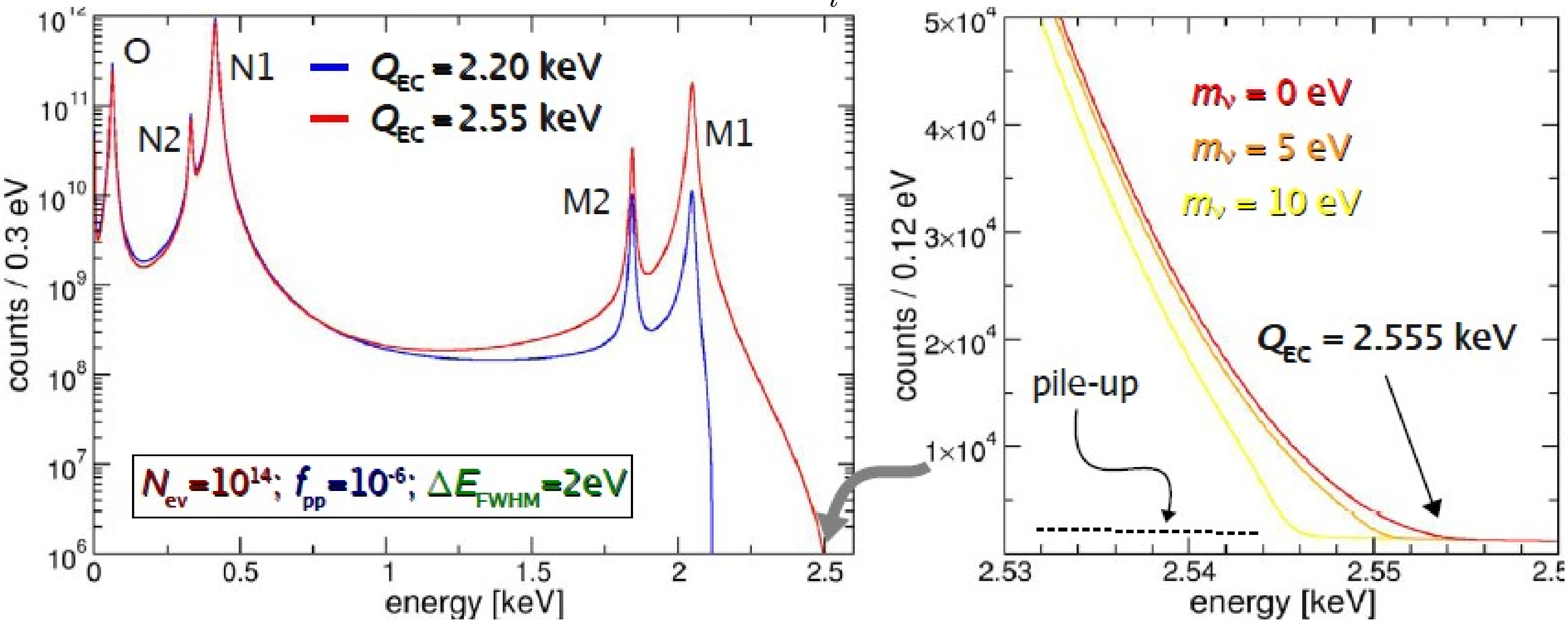
^{163}Ho EC measurement

- calorimetric measurement of Dy atomic de-excitations (mostly non-radiative)
- Breit Wigner M,N,O lines have an end-point at the Q value
- rate at end-point depends on Q_{EC}
  - →Q_{EC}? Measured: Q_{EC} = 2.3÷2.8 keV. Recommended: Q_{EC} = 2.555 keV
- $\tau_{1/2} \approx$ 4570 years: few active nuclei are needed
- ^{163}Ho production by neutron irradiation of ^{162}Er enriched Er

$^{163}Ho + e^- \Rightarrow {}^{163}Dy^* + \nu_e$

electron capture from shell ⩾ M1

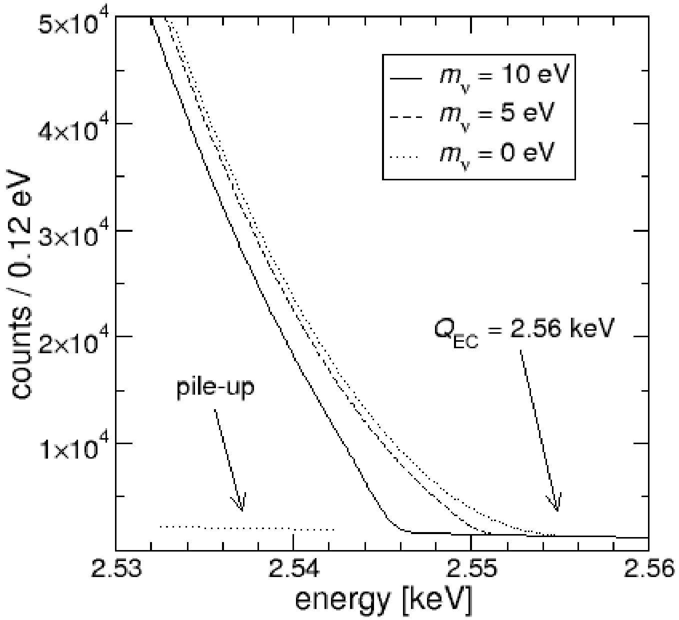
$$\frac{d\lambda_{EC}}{dE_c} = \frac{G_\beta^2}{4\pi^2}(Q-E_c)\sqrt{(Q-E_c)^2-m_\nu^2} \times \sum_i n_i C_i \beta_i^2 B_i \frac{\Gamma_i}{2\,\pi}\frac{1}{(E_c-E_i)^2+\Gamma_i^2/4}$$



A. De Rujula and M. Lusignoli, Phys. Lett. B 118 (1982) 429

The HOLMES project

The **HOLMES** experiment is aimed at directly measuring the electron neutrino mass using the **electron capture (EC) decay of ^{163}Ho.**



Goals

- probe the electron neutrino mass down to 0.4 eV
- prove the scalability of its technology to a larger experiment that will explore the neutrino mass region down to 0.1 eV.

LTDs

- low thermal capacity absorber coupled to a sensitive thermometer (TES) to measure the temperature rise caused by an energy deposition.

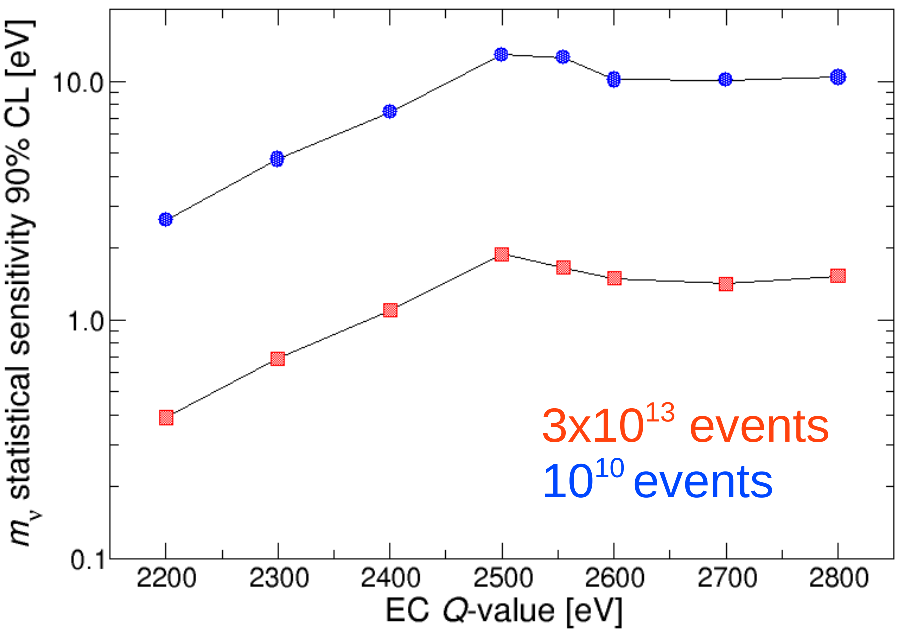
The experiment will start in 2014 and it is characterized by 4 key points:

1- ^{163}Ho isotope production
2- TES detector array development and optimization
3- SQUID read out and multiplexing
4- Analog/digital signal processing

The HOLMES project has been recently approved by the European Research Council – Advanced Grant (PI: Prof S. Ragazzi)

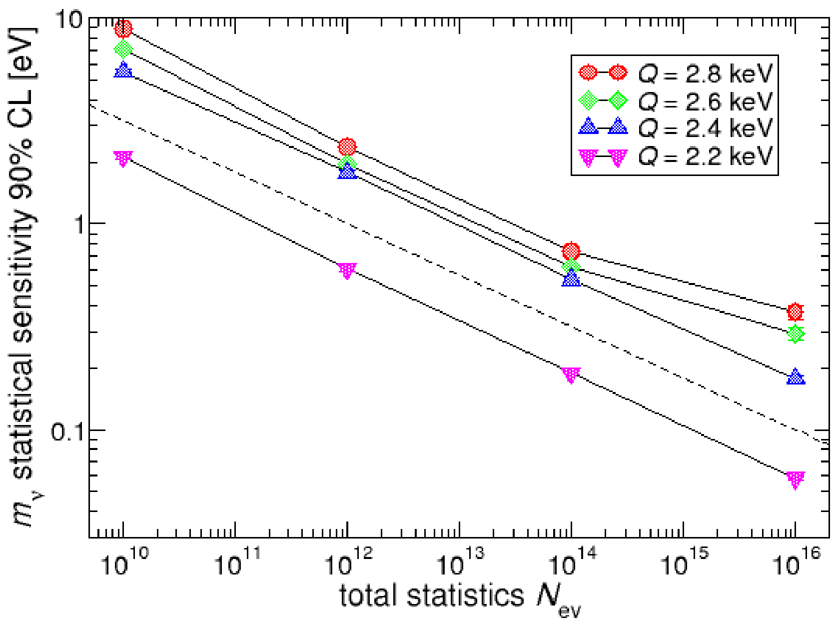
Neutrino mass statistical sensitivity - HOLMES

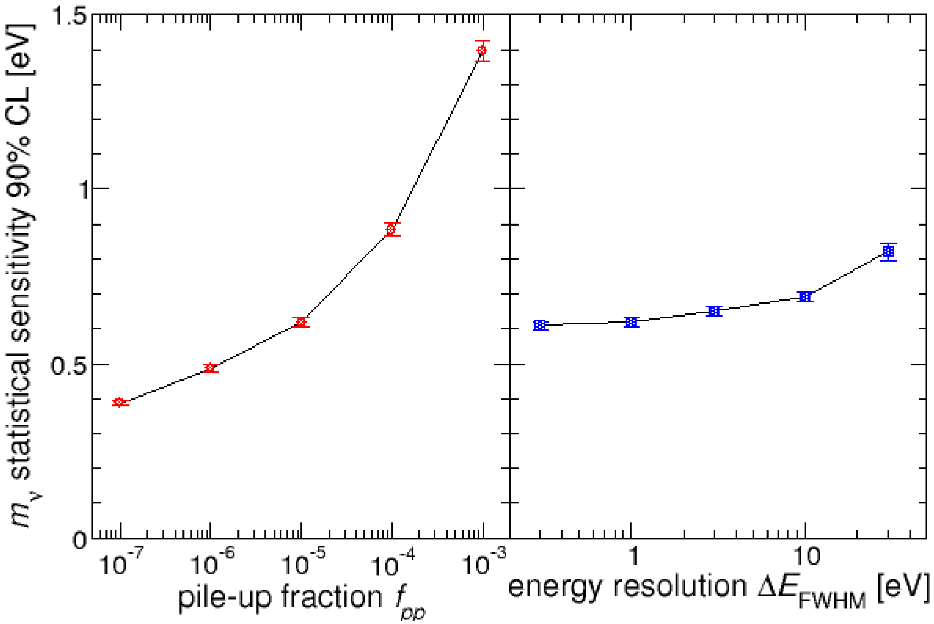
MonteCarlo estimate of Holmes neutrino mass statistical sensitivity



- 1000 detectors – 3 years live time
- Activity of each detector 300decay/s → 3x10[3] events

- With an energy resolution of 1 eV and a time resolution of 1 μs the neutrino mass statistical sensitivity ranges from 0.4 to 1.8 eV (90% CL) for Q value between 2.2 and 2.8 eV.





^{163}Ho

Goals:

Production of metal absorber with ^{163}Ho metal homogeneously embedded in.

Issues:

✔ Production of ^{163}Ho: neutron activation of enriched ^{162}Er oxide

Er-162(n,γ)Er-163 ➔Ho-163 (3 irradiations in the last 2 years)

- Purification: under study with different methods (PSI, LANL)

✔ Reduction to metal form: recently demonstrated (Genova).

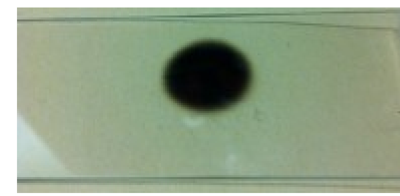
- Embedding in the absorber: first test done

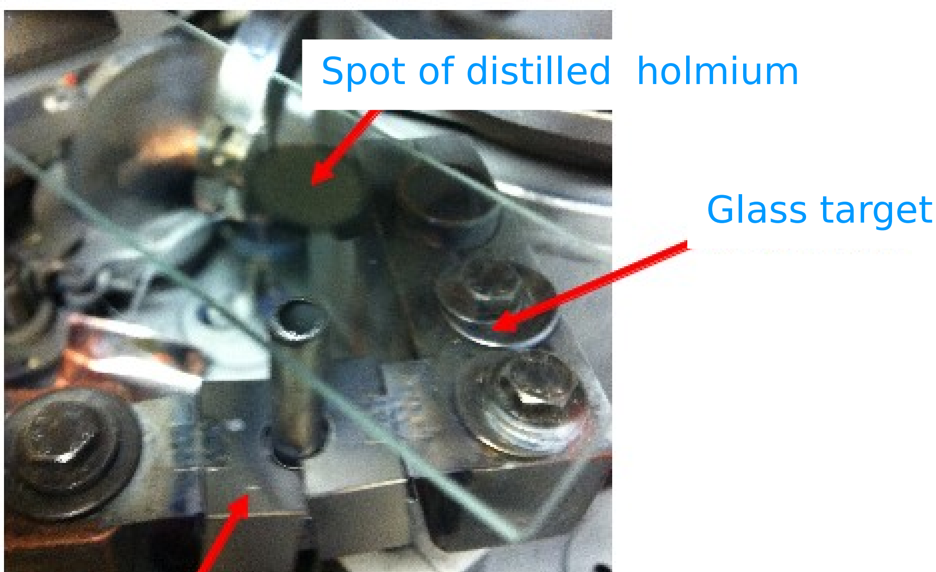
In a Knudsen Cell at about 2000 C

$$HO_2O_3+2Y(m) \rightarrow 2Ho(m)+Y_2O_3$$

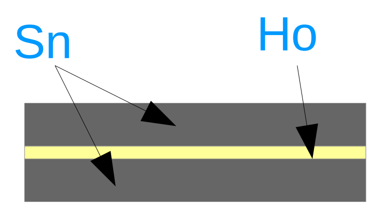
Ho(m) is then distilled onto cold target

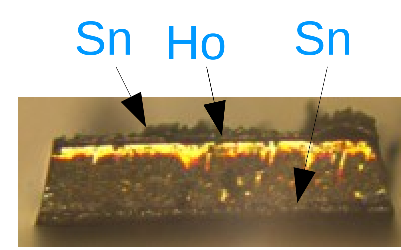
Spot of the distilled holmium

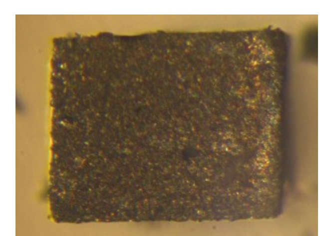




Tantalum Knudsen cell used for distillation of Ho(m)

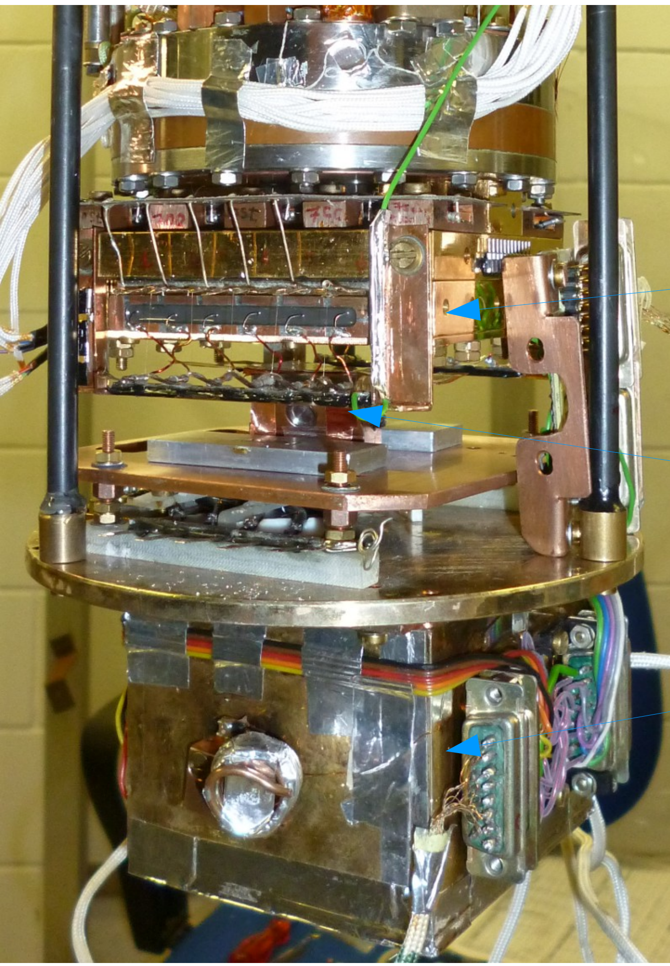






^{163}Ho

Two runs aimed to test the new absorbers made of Sn/Ho/Sn are performed @ Milano-Bicocca.
The absorbers are glued on Si thermistors.
The cryogenic set-up and electronics are the one used in the Mibeta experiment as well as the dilution unit.

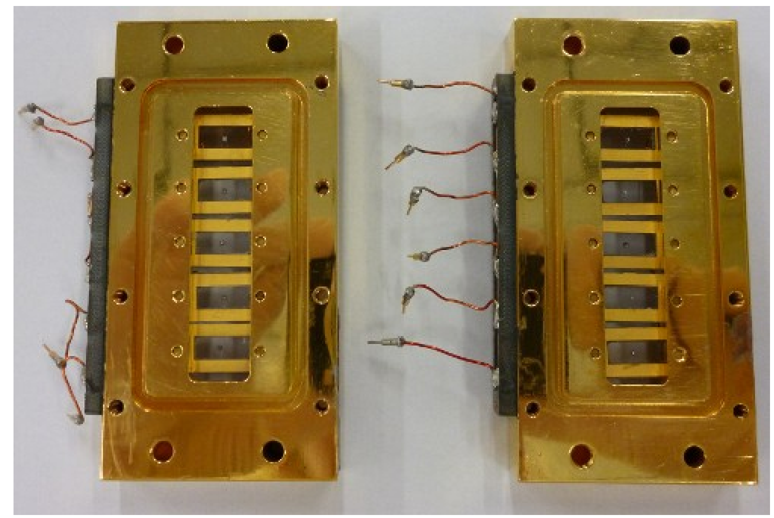


Detector holders mounted under the MC

55Fe calibration source – Al, F, NaCl targets

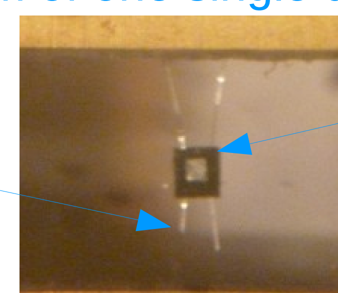
Cold electronic JFET

10 detectors: 9 with Ho and 1 with Sn



Zoom of one single detector

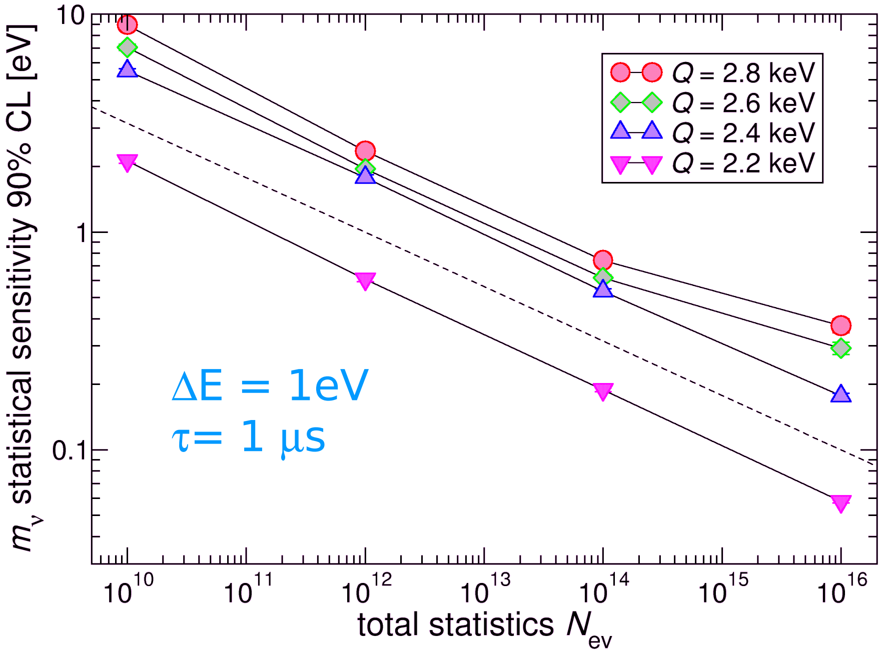
Al bonding wires



Sn/Ho/Sn absorber Glued on Si thermistor

The analysis of the first acquired spectra is ongoing. From the first observations, it seems that a purification work has to be done.

^{163}Ho & MKIDs

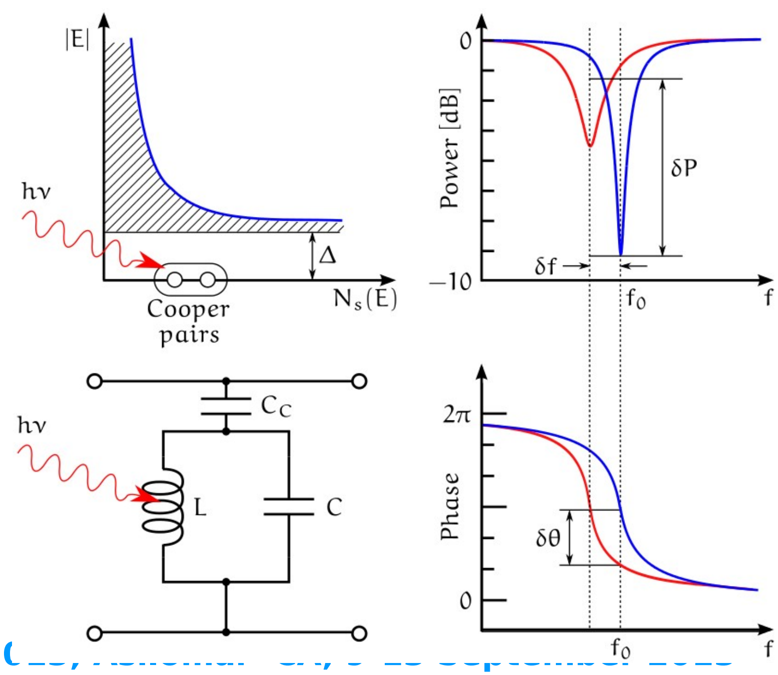


Sub-eV sensitivity on neutrino mass with ^{163}**Ho EC** (from shell >> M1)

Requirements:

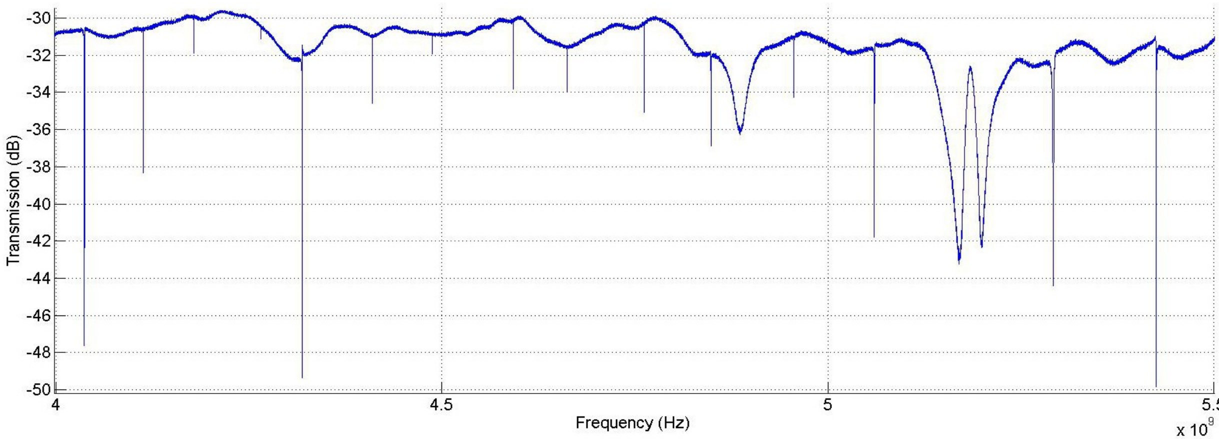
- ✓ High energy resolution (eV)
- ✓ Fast response detectors (tens µs) to avoid pile-up events
- ✓ Multiplaxable array detectors (10000)

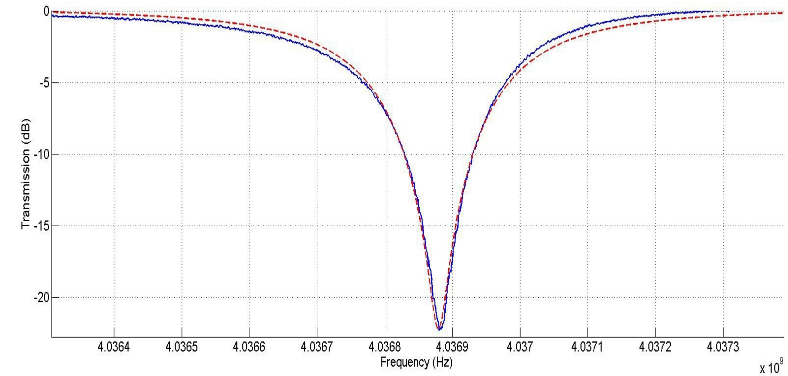
MKIDs

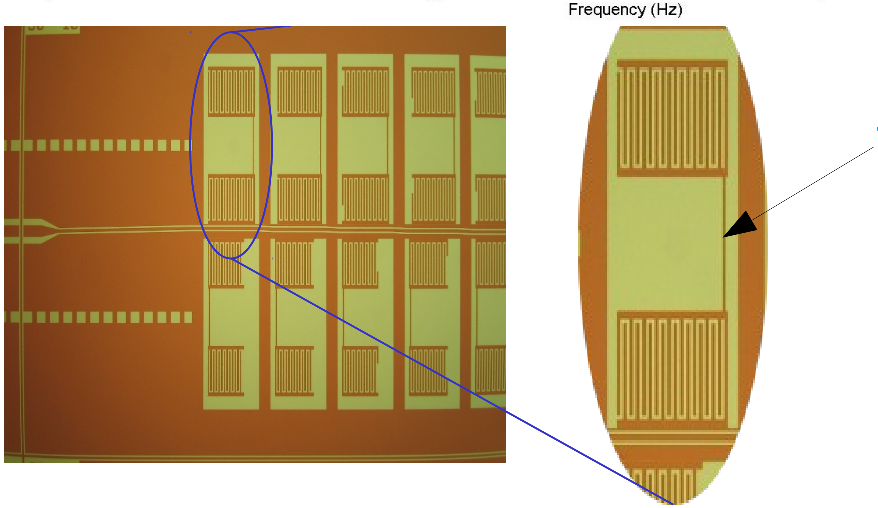


- resonator exploiting the *T* dependence of inductance in a superconducting film
- **detectors** suitable for large absorbers
- **Good time resolution** (low pile-up f_{pp})
- **high energy resolution**
- **multiplexing** for very large number of pixel

MKIDs for ^{163}Ho EC decay end point





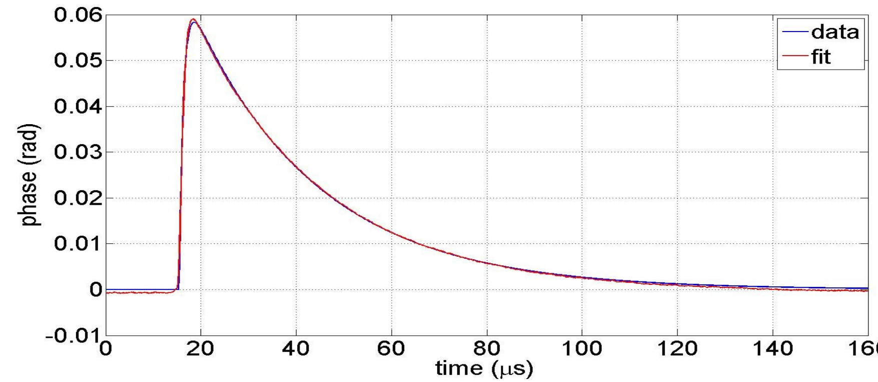


The ^{163}Ho will be embedded in the center of the inductive part of the resonator, deep enough to ensure low escape probability. A thickness of <500nm will be enough

10^{12} Ho nuclei are needed for a count rate of 10 Hz

theoretical resolution

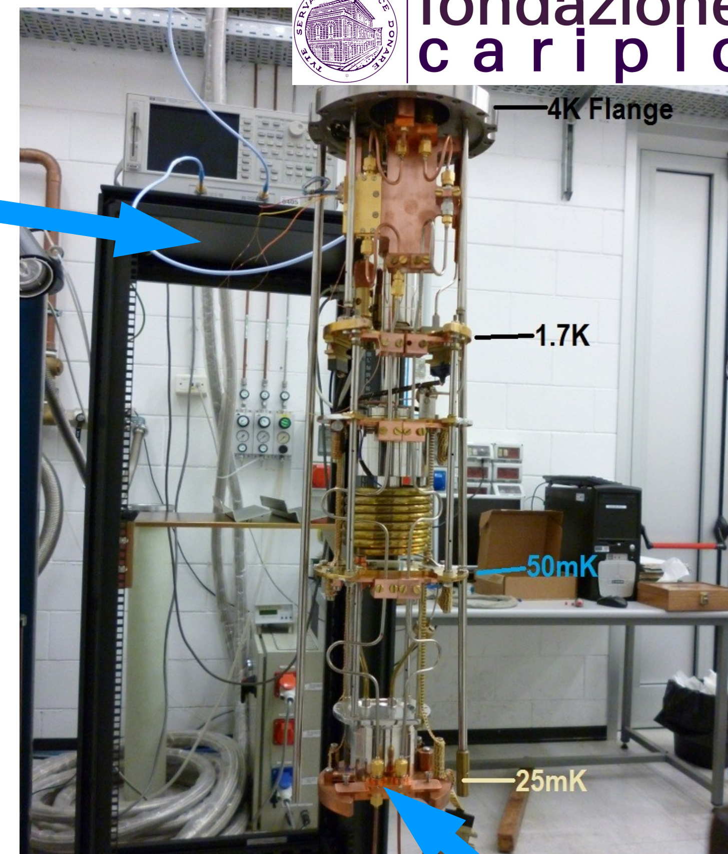
ΔE_{th} = 1.5 eV @ 2keV

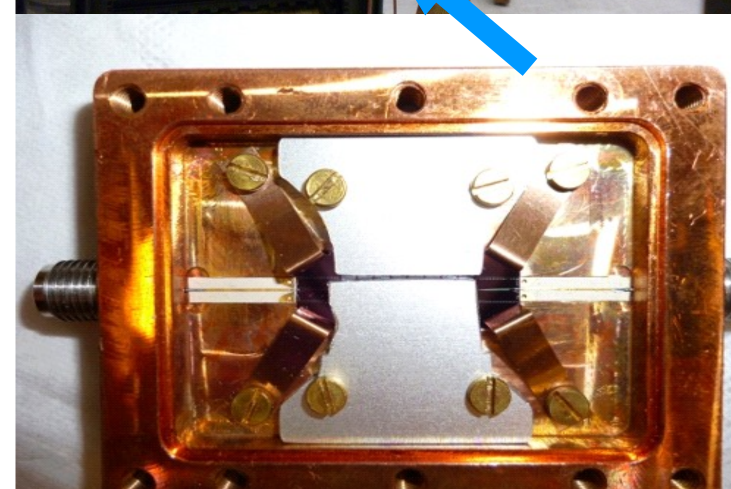


This work is supported by Fondazione Cariplo through the project "Development of Microresonator Detectors for Neutrino Physics" (grant 2010-2351).

MKIDs for ^{163}Ho EC decay end point measurement

4-12 GHz
cryo amp





So far tested stoichiometric TiN films, sub-stoichiometric TiN films and Ti/TiN multilayer (produced by FBK), which behaves like a sub-stoichiometric TiN film

Film	Tc(K)	Δ (meV)	Qi
Stoichiometric TiN	4.6	0.8	10^5
Sub-stoichiometric TiN	2.5	0.39	10^6
Ti(10nm)/TiN(15nm) 8 layers	1.6	0.26	10^5
Ti(10nm)/TiN(12nm) 8 layers	1.2	0.17	$5x10^4$

The devices were tested with ^{55}Fe (6keV) and Al X-ray (1,5keV) and the first pulses were acquired. Not resolving yet because of events interacting in the Si substrate under the superconductor.

Suspended inductor: no contact between the sensitive part of the detector and substrate to prevent phonon event from the substrate and losses into substrate

Conclusion

First array of MARE-1 has been assembled

→ 31 thermistors are equipped with $AgReO_4$ absorbers

The goal performances of the detectors have been achieved

→ first spectra were acquired obtaining a resolution of ~28eV @ 1,5keV

The HOLMES project has been recently approved by the European Research Council (PI: Prof S. Ragazzi). It will start in 2014 (Ho & TES)

First samples of Ho(m) are produced and embedded into absorbers

→ First runs to test Ho absorber produced by Genova are ongoing

In the meanwhile new detector technology under investigation

→ ^{163}Ho EC measurement with MKIDs